United States Military Academy (USMA) Space Engineering and Applied Research (SPEAR): A Cadet's Idea Becomes Reality

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ABSTRACT

Last year, the United States Military Academy (USMA) graduated its first cohort of fully qualified Space Professionals. The Class of 2020 included the first graduates of USMA's Space and Missile Defense Program. The program was born out of a capability deficit identified by COL Thomas Pugsley, the founder of the Small Satellites Research Group at West Point, over 12 years ago. This was detailed in his paper, Army Space Education: Closing the Gap with Operational Space, presented at the 23rd Annual AIAA/USU Conference on Small Satellites. This new program has ignited inspiration among the Corps of Cadets. A couple of cadets within Mechanical Engineering major field of study approached the Physics and Nuclear Engineering (PaNE) Department, which administers the Space Science Program, to pitch their idea for a cadet rocket program. As an organization that simulates and encourages cadet creativity and initiative, PaNE happily assigned faculty advisors and the Space Engineering and Applied Research (SPEAR) project was born. The initial effort centered around a national collaborative rocket launch dubbed "Operation Space." In the summer of 2019 cadets from SPEAR in concert with members of Operation Space from around the country successfully launched a two-stage solid rocket from Spaceport America in New Mexico. Since then, SPEAR at West Point has grown to be much more than a cadet led rocket project, although that is still a large part of it—and big draw for cadet participation. SPEAR now encompasses all space related research and development activities from across the Academy and will soon begin operation as a club activity under both the Mechanical Engineer Club (hosted by the Civil and Mechanical Engineering Department) and the Astronomy Club, (hosted by PaNE). The challenge now is to tend this growing fire of inspiration and to keep it alight as a beacon to bring new cadets and cadet candidates into the space enterprise.

INTRODUCTION

During the 2021 Academic Year (AY) the United States Military Academy has continued to grow its Space Science Program and related activities despite the challenges of operating in the COVID environment. This paper details the events of the last academic year and provides a look at how one cadet's vision for space at West Point has inspired others to become involved in one of the fastest growing programs at the Academy. This paper is the third in a series of submissions to the Small Satellite Conference which chronicle the beginnings, challenges, successes, and continued growth of modern space education at West Point.

If you wish to have a full understanding of the driving factors for the establishment of the Space Science Program at USMA, reference COL Pugsley's submission to the 23rd annual Conference on Small Satellites, *Army Space Education: Closing the Gap with Operational Space* (SSC09-XII-2). My previous submission to the 34th Small Satellite Conference, *USMA Space Cadets: The First Class* (SSC20-WKV-10), covers the eleven years between COL Pugsley's suggested way forward and the graduation of USMA's first Space Science majors.

The establishment of a formal program, dedicated to the development of space professionals, has been long and fraught challenges. For the staff, faculty, and cadets of USMA challenges are welcome and adversity is appreciated. That is why the Space Science Program has the fastest growth of in the Department of Physics and Nuclear Engineering and is on track to become the largest major in the department.

FORGING A SPEAR

"He needed a lot of explosives" [1]

In 2018 CDT Brandon CEA, a mechanical engineering major at West Point, was approached by a high school friend, Mr. Joshua Farahzad, regarding participation in an endeavor he was leading called "Operation Space."[2] This was going to be West Point's first push into the realm of launch vehicle design and operations. However, they needed to get some buy in from an academic department to get involved and provide the support Mr. Farahzad's project needed. Unlike civilian

institutions and their students, service academy cadets cannot simply break out from their highly regimented schedule to follow their passion. This does not mean the opportunity is denied, only that there is some more rigor involved with engaging in the pursuit.

Officially established in May 2018[3], Operation Space had several ambitious goals but perhaps the most important is captured in the following statement. "Our goal is to give students from across the nation the opportunity to work with their other talented peers and inspire students across the country by showing them that many things they've deemed out of the reach are actually very possible." With the new Space Science Program established at West Point and inspired by this opportunity with Operation Space, CDT Cea knew it was time to set out and gain support to pursue his passion.

In September of 2018 CDT Cea approached his Physics II instructor LTC Jacob Capps, an Army Aviator turned Academy Professor, to pitch his idea of supporting Operation Space. In October LTC Capps agreed to advise CDT Cea and two other cadets, Jared Hudspeth and Chase Lewis in what would become USMA Space Engineering and Applied Research (SPEAR). COL Chapman, the Deputy Department Head of Physics and Nuclear Engineering (PaNE) said this of the project, "if a cadet is interested in something, and it has Army applications and great potential for academic development, we couldn't say 'no'."[4]

Aside from the personnel connection between Mr. Farahzad and CDT Cea, there was another good reason to join forces. Operation Space needed somewhere to test, somewhere launch, and their rocket needed an ignition source for the second stage which meant explosives. West Point and the Army could potentially provide both, so the deal was struck. Operation Space would provide the rocket and SPEAR would work the logistics of test ranges, launch ranges, and explosives purchase and handling.[5]

Launch Slips are Normal

Anyone who follows news about space knows that a slip in a rocket launch date is a regular occurrence, especially for orbital launches. Launch windows are narrow, payloads get delayed, testing uncovers a defect, weather moves in, an unknowing general aviation aircraft violates the airspace. Those and a hundred other reasons can lead to a launch slip for a perfectly orchestrated and professional launch team. The Operation Space team had its own basket of setbacks along the way. "The batteries failed, the computers stopped working, and various pieces got stuck. The parachute didn't open, and the students were chased off the field by enemy flying objects called mosquitos."[6] And that was only during an attempt to complete a single test. The initial "early winter"[7] launch date was not going to happen.

Shortly after the failed parachute test is when SPEAR was established at USMA. The teams started collaboration and planning began in earnest. "That jump-started their progress. They spent the school year honing their designs and securing...parts." At this time, it was apparent that commitment required from the cadets was much more involved than an extracurricular club activity. In "spring 2019 (PaNE) decided…the time and effort spent on SPEAR was equivalent to a 289-389 course, therefore (PaNE) changed it to become more of a research team and assigned every member with a professor to assist with research and design of a static fire test base and (second) stage ignition system."[8]

The team was now pressing for a summer launch from Spaceport America. There was much to accomplish is a relatively short time. "Between October 2018 until summer 2019 there were multiple visits…to Princeton"[9] where the teams would collaborate.

Test Once, Launch Twice

West Point brought a couple vital capabilities to the Operation Space collaboration. One, as a DoD entity they could legally procure, and store controlled explosive materials. In this case the $BKNO_3$ which was critical to ignition of the second stage. Two, they had ample ranges with the necessary safety infrastructure and controls required to conduct static fire tests of the rocket motors to validate the function of the ignition system.

On April 27, 2019,[10] the team assembled at West Point for the static fire test. Just over a month out from launch, it was a critical event. It would validate the ignition system functioned properly. The test would also prove the value of the collaboration with West Point and that the USMA cadets could deliver. The test was a success.

Figure 1: Static Fire Test

The teams were ready to head to the New Mexico desert for their attempt to traverse the Kármán line. In May 2019, the SPEAR cadets along with two of their faculty advisors, MAJ Jill Rahon and Dr. David Hutchinson accompanied the team from Operation Space to Spaceport America in Truth or Consequences New Mexico, adjacent to the Army's White Sands Missile Range (WSMR). The teams got to work making final preparations to launch two rockets. Setting up and securing the launch rail, final assembly and testing of the rocket's forward section and avionics, and finally mounting the rocket to the rail.

On 31 May, the 17-foot-long rocket zoomed skyward. Its second stage ignited but lost a fin and broke up at an estimated 100,000 feet altitude. A second attempt was made on June 1st. The launch was a success, but the rocket did not quite make the 100 km altitude goal. Despite not reaching the desired altitude there was much to be proud of. If it were easy, it would not be rocket science. A dynamic and diverse team of students from across the country came together to with a unified goal and made it happen. That was just the beginning for the cadets of SPEAR.

Figure 2: 2019 Launch

THAT WAS AWESOME! WE CAN DO BETTER.

Credit Where Credit is Due

After the conclusion of the summer 2019 launch campaign the cadets were hooked and knew they had to try again, but this time it would be a USMA centric project. The PaNE advisors discussed with the department leadership and decided, since the preponderance of participating cadets were majors in the Department of Civil and Mechanical Engineering (CME) it made sense to host the project there and make it an engineering capstone. The capstone was the appropriate level due to the increased technical and academic rigor that comes with it. It represents the core of the effort but there are several cadet independent research activities which tie into the capstone.

Designated as x89s, cadet independent research courses offered at the 1, 2, or 3 credit hour levels. These are designed to give cadets the appropriate credit for the work they do. Many times, cadets are enrolled into an x89 because we know they would do the work anyway, without credit. We want them to get the credit that is due for their hard work. Most of the supporting x89s are SP289 or SP389, the SP designating the course is part of the Space Science Program and the proceeding number denotes the credit level of the course. The multidisciplinary nature of the project and the fact PaNE is home to the Space Science Program and the Space and Missile Research Analysis Center (SMDC-RAC) ensures PaNE's continued support to the project.

Make no mistake, now an official engineering capstone in an ABET accredited program, it is a cadet led endeavor. Faculty advisors help to guide cadets down the path of their choosing and grade them along the way. They also assist with outreach and coordinate opportunities to secure funding for the effort. Cadets are given the chance to lead, make critical decisions, and test hypothesis. Most importantly they are allowed fail. The cadets all follow current events in the space and technology sectors. They can relate to Elon Musk's mantra, "If things are not failing, you are not innovating enough."[11]

A USMA Centric Model

Figure 3: SPEAR Logo 2

Following the successful launch in summer of 2019 the capstone team knew they had the knowledge, skills, and experience to begin development on their own two-stage sounding rocket. They decided to drive on with a lofty long-term goal in mind. To develop a low-cost, low-earth-orbit (LEO) capable rocket whose purpose is replenishing space-based capabilities for the Army and the DoD in the event of denial, disruption, or destruction of a currently on orbit asset. The cadets dubbed their system the Immediate Critical Antisatellite Response Utility System (ICARUS) because every good DoD program has a cool acronym for a name. More importantly, it shows that the cadets are truly preparing for their role of leading in the Army that is

focused on multi-domain operations. They can see the potential threats which are present today and know that it is a problem that needs to be addressed now and into the future.

The groundwork was laid, and the team began evaluating the good, the bad, and the ugly of the Operation Space endeavor. The good, they had successfully gotten two rockets off the rail and the second stage ignited. The bad, both rockets failed to meet the mark of the 100 km altitude and had critical failures on the way up. The ugly, the number of logistical challenges involved with split operations, moving hazardous material across the country, and not having a separate source to validate the performance of the rockets. These and more needed to be addressed if USMA cadets were going to succeed.

The cadets started laying the framework for ICARUS as the capstone with CDT Cea taking the lead. "SPEAR will develop the Immediate Critical Antisatellite Response Utility System (ICARUS) project, a rapidly deployable, cheap, and disposable system designed to mitigate ASAT effects by delivering replaced lost satellites and ASAT tracking satellites to Low Earth Orbit (LEO) through the means of a multi-stage solid state guided rocket."[12] This bold plan called for parallel development of a LEO capable rocket, a CubeSat payload, and operations support equipment and personnel. While this is still the long-term vision for SPEAR, guidance from the faculty and a couple outside advisors helped the cadets realize an iterative approach is a more feasible approach with regards to scope of work and cost for a yearlong capstone. Joseph Maydell of Space Launch Tech, who supported the Operation Space endeavor and assisted the team's 2021 capstone, said this, "You should never underestimate the amount of time, effort, and diligence required for successful space flight. Among other things it requires thorough engineering analysis, diligent acceptance testing of all manufactured parts, exhaustive vehicle integration testing, and well-written operation procedures."[13]

WELCOME TO THE COVID ENVIRONMENT

2020 an Academic Year like No Other

In March of 2020, the cadets of West Point were on spring break leave as were much of the staff and faculty. The term novel coronavirus (COVID-19) was flooding the news. My family and I were finishing our first trip to Disneyworld when they announced they would close to visitors, luckily it was the day we left. Cadets were instructed to hold in place. "Lt. Gen. Darryl A. Williams, superintendent of the U.S. Military Academy, announced March 19 that the Corps of Cadets would not be returning from spring break as planned."[14] This was a shock to everyone, cadets, staff, and faculty alike. The methods for training, education, collaboration, and operations as whole would change forever.

Work on research projects was now the last priority. There were two things that must be managed immediately: 1) return and graduation of the first-class cadets 2) continuation of the academic year for all cadets via a remote means. This was no simple task and the effort to make those two things happen were absolutely a monumental undertaking. It is rare that the Army does not have a plan that they can pull from the shelf, dust off, and put into action. The nature of the virus and its effects are serious, and all precautions needed to be in place for cadets, staff, faculty, and their families before the first class, and the lower classes following, could return.

Everyone was on lock down. All activities were migrated to MS Office 365 and its associated products. Meetings were all through MS Teams and there was a shift of all course content to an online medium that cadets, staff, and faculty could access from their homes. Some cadets had to be sent their school computers since they had not taken it with them on spring break leave. The remainder of the semester was completed remotely.

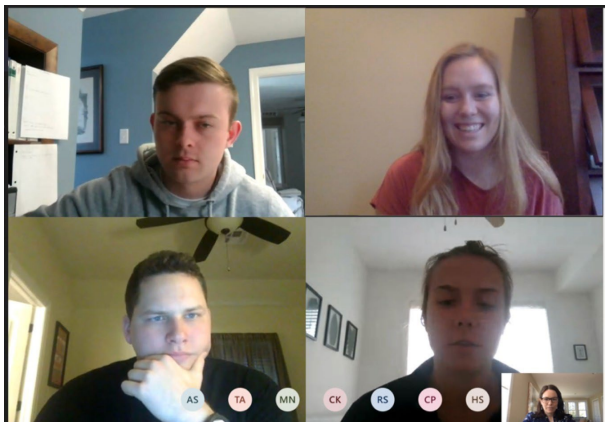

Figure 4: USMA Geography Class from Home[15]

During the rest of the academic year a plan was put in place to bring the first class back for graduation and to get them out the door to their first assignments as Lieutenants in the United States Army. In parallel a new method of operating at USMA in the COVID environment was enacted. Cadets returned in cohorts, were tested, and quarantined. The class of 2024 was brought in for a historic R-Day and their experience was unlike any other which spurred their class motto, "Like None Before, 2024."[16] Many summer training requirements were cancelled, deferred, or waived. The academic departments readied their facilities and their

curriculum to support learning in the COVID environment. Socially distant, masked-up, in-person, remote, or hybrid classes. Cadets would be on campus, and research could start up again.

LONG BREAK, NO BREAK, BREAKNECK

As part of the plan for the 2021 Academic Year the schedule was amended to allow cadets to have a break between semesters while meeting the travel and quarantine requirements at the federal, state, and local levels. To accomplish this winter break was extended, spring break was eliminated, and multiple 3-day weekends were added to the spring semester. In addition, changes were made to class period times to allow for the one-way traffic flow in buildings to help lower congestion and keep distance between cadets.

It was a lot to adjust to and it took a toll on cadets, staff, and faculty alike. The USMA team is strong, we have a mission "to educate, train, and inspire the Corps of Cadets so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country and prepared for a career of professional excellence and service to the Nation as an officer in the United States Army." We owe it to the Army and the Nation to successfully execute that mission no matter the challenges we face in doing so. We Solider On.

"Focus is a matter of deciding what thing you're not going to do" [17]

Given the restrictions associated with operating in the COVID environment during AY 21 the assumption for SPEAR was that there was a very low probability of a launch in the spring or summer. The cadets knew that the full ICARUS project was too much and had decided on an iterative approach to development of the launch vehicle portion of the system. With no launch on the horizon the team needed to decide what the capstone would produce. The decision was made to focus on refining the second stage ignition system. In concert with the capstone team, a team of cadets from Geography and Environmental Science (GENE) and Chemistry and Life Science (CLS) advised by faculty from CLS and PaNE embarked on an independent research project to develop processes and procedures for manufacture of $BKNO_3$.

The reasoning for the project choices tied back to the Operation Space launch in 2019. The cadets had experience with the development of the ignition chamber for the Operation Space launch. There was a suspicion that something in the second stage was causal to the failures, so the sustainer would be the focus. The refinement of the design of the second stage ignition system increased reliability and in-turn probability of mission success. Also, because the chamber is a novel design there is a possibility of pursing a patent on the system.

The decision to the pursue cadet manufactured $BKNO_3$ was threefold: 1) Shipment of the ignition material falls under CFR 49 as a hazardous material which makes shipping costly and requires special certification 2) The material is expensive to procure from commercial vendors and can have long lead times 3) The capstone team needed ignition material to complete static fire tests. Apart from the practical reasons, the cadets just had a genuine interest in the project and dove into the research.

Fortunately, despite the difficulties created by working in the COVID environment, the advisory team was still able to work on securing funding for the capstone and the associated independent research projects. Since there was no launch campaign in 2020, it allowed for required purchases to be made and equipment to be set and readied for the AY 21 effort. When the cadets returned, they were ready to get to work. There was still optimism within the team that there would be an opportunity to launch in the spring, so it was penciled in as a tentative goal. Validation of the second stage ignition system functionality, performance of cadet manufactured $BKNO_3$, and sustainer performance motor performance were the priorities for the year.

Thankful for Online Shopping

The goals were set, and the teams got to work. They had a cabinet full of rocket fuel and other explosive materials to work with. Through constant correspondence over the summer, the cadets relayed the list of the other desired equipment they would need to succeed. With all-hands working remotely we had to adapt to working in a fully virtual environment while still meeting mission requirement. In addition to the full cabinet, there was a new test stand with a Futek sensor package, rocket bodies, liners, and nozzles for the sustainer and booster. It was like Christmas with cadets coming in to open all the goodies that were awaiting their arrival.

To meet the overall performance and cost goals of the ICARUS project the cadets chose to go with commercial-off-the-shelf (COTS) solid rocket motors. To achieve the performance required to meet the goal of traversing the Kármán line the cadets found there was not a single COTS system that had the performance required. The solution was mating two powerful COTS motors in a two-stage configuration. The challenge being the motors are designed as single stage disposable motor systems (DMS). Design and development of an interstage connection would be required and the cadets

second stage ignition system would have to perform as expected.

The AY 21 capstone rocket design consisted of a first stage (booster), an Aerotech O5280X-PS DMS[18], and the second-stage (sustainer), a Cesaroni Pro75-6GXL-IM[19]. With the cadets focused on the second stage ignition system they looked to Space Launch Tech for expert assistance in manufacturing some of the other required components to make a complete launch vehicle. CDT Cea and the SPEAR team met Mr. Joseph Maydell, CEO of Space Launch Tech and founder of High-Altitude Science, at Spaceport America during 2019 launch campaign. High Altitude Science was one of the sponsors of Operation Space. The team knows Mr. Maydell's passion for space and space education. His shared knowledge and enthusiasm would be a great asset to SPEAR.

Figure 5: Mr. Maydell on Console, NASA-JSC[20]

Test, Test, Test

Cadets had enough hardware in-hand to work with to make meaningful progress toward their goals during the fall semester. The culminating event for the capstone was to conduct a static fire test of the second stage motor to validate the function of the ignition chamber, the performance of cadet manufactured $BKNO_3$, and performance of the COTS motor against advertised specifications. To perform the test cadets had to accomplish several subtasks leading up to the full static fire test itself.

First, the team had to refine the design of the ignition chamber based on data from the 2019 launch. The method of integration and attachment to the forward enclosure was an area of concern. Initially the chamber was attached with a piece of all thread which secured on the backside of the forward enclosure with a nut. The desire was to fully integrate the chamber into the forward enclosure and mill as a single part. The test chamber was milled out of steel. While heavy, it was thought it would maintain structural integrity through ignition and burn of the second stage.

Second, the cadets needed to integrate the new Futek sensors into their new test stand. The new test stand was also a COTS item and was an open frame design. It was lighter and easier to manage than the teams custom test stand used to support Operation Space. The first test stand was designed with safety as the priority. It was built to withstand and contain a potential catastrophic failure of a booster sized motor.

Third, the cadets working on the process and procedures to manufacture the require ignition material had to successfully produce usable pellets. Deemed Team BPN (Boron Potassium Nitrate), after the main chemical components of the ignition material, they began their work in a small lab in the basement of Bartlett Hall. Many hours of mixing, mashing, and molding were to follow.

The teams drove hard throughout the semester and achieved a multitude of steppingstone successes leading up to the milestone static fire test of their second stage motor. Team BPN came through, after several failed attempts, with a viable one gram $BKNO_3$ pellet which resembles the caffeine pills it was modeled after. The rebranded SPEAR-HRT conducted an open-air test of their next iteration ignition chamber validating structural integrity and ability to hold the pellets throughout the ignition process. The test stand was instrumented and configured to hold the 75mm sustainer motor. "The multi-disciplinary Space Engineering and Applied Research-Hypersonic Rocket Team (SPEAR-HRT)[1] conducted a static fire test of their second stage solid rocket at Range 12 on the December 2nd."[21]

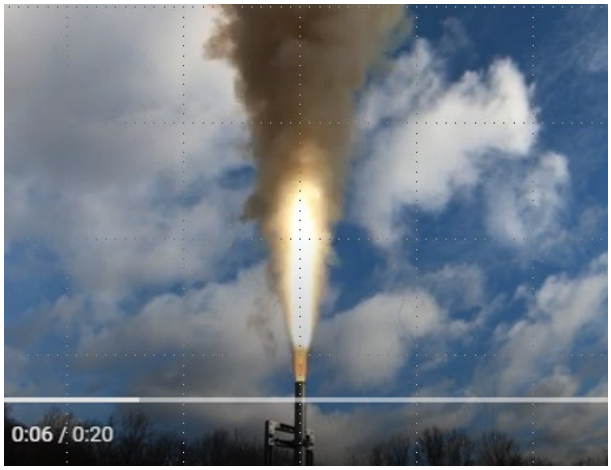

Figure 6: Go-Pro of 2 Dec Static Fire[22]

[1] SPEAR added the HRT for a couple reasons. 1) It aligned with the goals of the team and interest of the sponsoring agencies 2) SPEAR was becoming more than just the rocket, it was going to start as a cadet academic club and would be inclusive of all space research activities at USMA.

In the meantime, faculty advisors were working hard to secure funding to support the project and began to look at potential plans to support a launch campaign in the spring semester. The probability of it happening were still very low as COVID cases were on the rise and restrictions on travel were tightened in response. There were some big questions that had to be addressed to make it happen, not even considering COVID. Where to launch, when to launch, who is going, how do we get there, and who is paying?

Well, that was Unexpected!

The December static fire test was a success on many levels. First, it validated the cadet manufactured ignition material would ignite the second stage within the required parameters. Second, it proved the test stand was viable and the sensor package performed as advertised. Finally, it added credence to the hypothesis that the initial design may have been causal to the cone-out of the second stage of the Operation Space effort and that a completely different material would be needed.

Following the static fire, after the motor casing had cooled adequately, the cadets pulled the forward enclosure which also contained the integral ignition chamber. To their surprise, the chamber was gone! It had melted under the intense temperature and pressure present within the rocket during the burn. In reviewing the video taken of the test, sputtering can be seen, and it is presumed the chamber material melted and became ejecta. Upon disassembly of the motor, damage was noted on the internal side of the nozzle as well as on the liner.

Figure 7: Ignition Chamber Remanence[23]

The problem was identified and there was a material consideration and decision that had to be made to move forward. However, the cadets we out of time for the semester. The next couple weeks the focus would be Term End Examinations (TEEs) and then a long winter break. There were two primary directions that would be considered: 1) A material with much higher heat tolerance that would stay intact or 2) A material that would hold the pellets long enough to achieve the required ignition before completely ablating without a potential of damaging the rocket. The team had a month to think on it.

But first, the cadets had to attend a historic Army-Navy football game, played at West Point for the first time since World War II. Army shut out Navy 15-0 in an almost empty stadium shrouded in fog. Sports were being played. The entire Brigade of Midshipman had come to West Point. Could we get a trip section for the launch approved? Maybe the Army win was a good omen.

Figure 8: The 121st Army-Navy Football Game[24]

We can Launch! But how?

The long winter break was good for the cadets of SPEAR-HRT and Team BPN. However, everyone knew the spring semester would be a grind. This was the final semester for many of the capstone team cadets. Since they missed the opportunity to launch in 2020 the desire to make it happen before graduation was a serious motivation. It also meant that it would be an absolute sprint to the finish as generally no trip sections are approved within two weeks of TEE week. This set a launch date of no later than the first week in May.

There had been little consideration given to an actual launch because the restrictions of operating in COVID environment during the fall semester. There was an extensive list of things that had to be accomplished and the team was already way behind on all of them. First and foremost was a material solution for the redesigned

and functioning second stage ignition system. Luckily, the team had been in touch over the break and had been in continuing collaboration with Mr. Maydell. There was much debate regarding the use of titanium as solution because of its weight and ability to withstand high temperatures. It was decided the expense in procuring and machining was too high. After much consideration, the team chose a glass-epoxy laminate material that had desirable properties to the given application.

In support, Team BPN had refined their manufacturing procedures and could produce batches of pellets relatively quickly. They had moved on to optimizing the ratios for best performance and were starting on material quality testing. There was a concern about the pellets ability to survive forces due to launch and rocket spin rates. The initial tests produced positive results.

So, what other things must be accomplished to launch no later than the first week of May. The list includes, but is not limited to, the following:

1. Design, fabricate, test, and validate the ignition system (must do to complete capstone and graduate)
2. Secure a range to launch from (initial budget $25,000)
    a. Pacific Spaceport Complex, Kodiak, AK
    b. NASA Wallops Flight Facility, VA
    c. White Sands Missile Range, NM
    d. Vandenburg AFB, CA
    e. NASA Kennedy Space Center, FL
    f. Spaceport America, NM
3. Ensure there is a way to pay the range (a contract perhaps)
4. Secure transportation (initial guidance, no commercial flights)
5. Secure lodging (must be on a government installation…who knew White Sands Missile Range was such a popular spring training destination)
6. Procure or fabricate rocket parts
    a. Motors
    b. Fins
    c. Avionics
    d. Nose Cone
    e. Recovery System
    f. Interstage Coupler
7. Assemble rockets
8. Arrange for HAZMAT/Explosives shipping
9. Build shipping crates for rocket and support equipment
10. Redesign and fabricate a launch rail
11. Provide range all required documentation (most ranges are government organizations and we, the government, love forms)
12. Secure required FAA waivers (also government and as such, loves forms)
13. Secure funding/sponsorship to pay for everything
14. Pack up everything, correctly (correctly on everything related to shipping is important)
15. Request and receive approval from the entire chain of command of all involved up through Dean, Commandant, and Superintendent of the United State Military Academy, all of which are General Officers

With a team of experienced officers advising the project and a large support network of professionals in contracting, finance, logistics, and space launch operations from multiple departments all these tasks would be easily accomplished. Unfortunately, that is not exactly the case as we are an academic institution and not an ACAT-1[25] program office[2]. This is a cadet led project and it is designed to develop future space professionals, engineers, and leaders of character so it should not be easy. To get this done in under 4 months with a full course load, for cadets and advisors, would be a challenge.

Professional Hurdlers

Each item on the to-do list represents a primary or secondary task with several subtasks underneath. Each subtask represents some amount of time and effort to achieve. Each task represented a hurdle the team had to get over and there were a lot. To clear the hurdle, the team had to receive a positive answer, a yes, to their request. Sometimes the hurdles are low and the yesses come easy. Other times the hurdles are high and there is a stumble or fall and the hurdle goes down, and you must restart. The goal, of course, is to clear the hurdles as fast as possible without knocking any down. Then you win the race.

While we were running the hurdles COVID cases in the country and in NY were on the rise. Again, it was looking as if COVID might cause another lost launch

[2] ACAT I programs are Major Defense Acquisition Programs (MDAPs). A MDAP is a program that is designated by the Milestone Decision Authority (MDA). Dollar value for all increments of the program: estimated by the Defense Acquisition Executive to require an eventual total expenditure for research, development, and test and evaluation of more than $525 million in Fiscal Year (FY) 2020 constant dollars or, for procurement, of more than $3.065 billion in FY 2020 constant dollars. ACAT I programs have three sub-categories: ACAT ID, ACAT IC, and ACAT IB.

opportunity. We kept optimistic and kept working toward our goal of an early May launch. We even cleared a few hurdles. We secured funding from a few sponsoring agencies; Space and Missile Defense Command (SMDC), Office of Naval Research (ONR), Walter Scott Foundation, and DoD Space Test Program (STP). We started procuring the materials we needed to make the mission happen. Then we started a dialogue with several of the launch ranges.

We found that most of the ranges were excited to discuss the opportunities of hosting a cadet led project from West Point, but some presented serious mission assurance requirements and costs associated with obtaining their support. We had an ambitious project, and our team were not full-time rocket scientists or space operations officers. We needed flexibility and expedience and the big ranges were not going to provide that. Also, we could not meet their requirements or quoted costs.

The focus was on the Spaceports. The Pacific Spaceport Complex and the Alaska Aerospace team were very excited at the potential to have our team out. The price was right and the team in Kodiak are fantastic. They had also just been added to a USSF/USAF range support contract available to use through the Space Test Program. There were a few challenges with using their facility: 1) Logistics of moving people and equipment literally across the entire country 2) The launch elevation of the facility 3) Ability to recover the rocket.

Spaceport America was also excited about the potential to have the cadets return for a launch. Dr. Bill Gutman spoke very highly of the SPEAR team which supported Operation Space in 2019 and was happy to hear USMA had developed their own rocket for a space shot. There were also some challenges with Spaceport America: 1) Logistics of moving people and cadets halfway across the country 2) There was no contract available for use and no federal/military entity in support 3) There was no organic telemetry support.

I put a plan together that would meet all the initial requirements of budget, lodging, and travel that would take us to Kodiak to launch. While doable, there were several instances that it could get derailed if something did not go exactly right. It also would require that the team have everything ready to go a month earlier that the no later than date and that was not going to happen. Although we ultimately did not launch from Kodiak, making the connection paid off for another group of cadets. Working with an Army mission partner, Alaska Aerospace agreed to support an Advanced Individual Academic Development (AIAD) internship for four USMA cadet during the summer.

We decided Spaceport America would be the range for the launch. The cadets were familiar with the range and the requirements of launching from there. Spaceport America could support the proposed dates and had an agreement with WSMR for telemetry support. There are several government installations nearby for lodging. Most importantly for the mission, we launched from an elevation of 4,595 ft and we could recover the rocket. There were two hurdles to get over with using Spaceport America: 1) We could not secure military space-available flights, thus we would have to fly commercial 2) There were no contracts between the DoD and Spaceport America.

While the advisors worked to supply the team with needed materials and clear the hurdles on the programmatic side, the cadets were working to get over their own series of hurdles. The design, fabrication, and testing workload were significantly increased with the push to try for a launch versus a series of static fire tests. The team took on some eager new members to assist with the additional tasks associated with the launch rail and logistics. These cadets were recruited through the newly reinvigorated SPEAR club activity. This club, which was at the heart CDT Cea's vision for SPEAR, was beginning to coalesce during the spring semester.

The remaining months of the semester were a blur. Everyone on the team was in a dead sprint to make the mission happen. SPEAR-HRT completed the design and fabrication of the second stage ignition chamber using the new material and a better configuration. Team BPN settled on an optimized chemical ratio for the pellets and manufactured enough to support static fire testing plus one flight ready rocket. Advisors continuously provided guidance, mentorship, and support with clearing each hurdle as it arose. As seen on the previous page, there were many.

The team managed another successful static fire test of a second stage motor, validating the new ignition system. They adjusted the design of the launch rail and made the required changes to support the rocket and launch requirements. They were close to the finish and the apprehension was growing as only two major hurdles remain before the team could depart to execute the launch campaign. They still had to gain the appropriate approvals from the Dean, the Commandant, and the Superintendent. They also had to present to their advisors, peers, and sponsors at USMA Projects

Day[3], less than 24 hours ahead of the scheduled departure for Spaceport America.

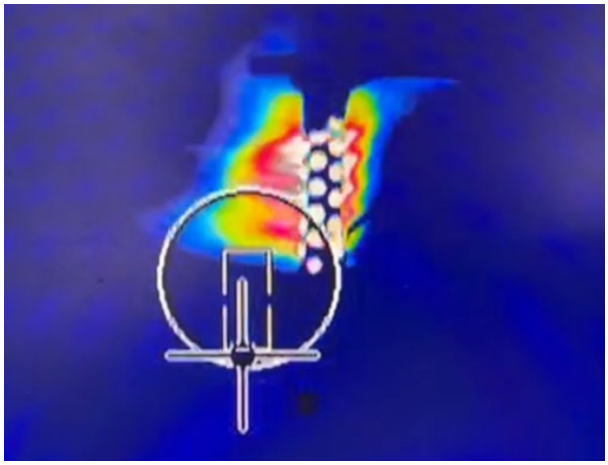

Figure 9: Thermal Camera Capture, Open Air Static Fire Test of Glass-Epoxy Chamber

On 15 April, the cadets of SPEAR-HRT and Team BPN were approved for travel to Spaceport America from 30 April 2021 to 3 May 2021. On 23 April 2021, the team found a method to transfer funds to Spaceport America under the recently approved Memorandum of Agreement. On 28 April 2021, the rockets and support equipment were received at Spaceport America. On 29 April 2021, SPEAR-HRT and Team BPN completed their projects day presentations and immediately following packed up for the 0300 departure the next morning. On 30 April 2021, SPEAR-HRT and Team BPN arrived in El Paso, TX and after checking in to their rooms at Ft. Bliss, made for Spaceport America's Vertical Launch Area.

On Time, Off Target

The FAA, WSMR, Spaceport America, and other coordinating agencies had approved SPEAR for a Saturday and Sunday launch window of 0600-1200. As if launching one rocket was not ambitious enough for the team, the primary concept of operations called for a launch, load, launch, recovery sequence. Meaning the first attempt would be made immediately upon opening of the launch window at 0600. If the first launch was nominal the second rocket would be loaded and launched as soon as possible. Teams would then split to recover the second stages where they landed. If the first rocket did not perform as expected, an anomaly occurred, then recovery and troubleshooting would become the priority over the second launch.

At 0200 on the 1st of May the team gathered in the lobby of the Ft. Bliss IGH to get the brief on the plan for the day's operation. Fueled by Starbucks Cold Brew, Monster Energy, and some tasty Walmart cinnamon rolls, a convoy of three rental 4x4s headed north into the darkness. At around 0350 we entered the "Genesis" roundabout and made a slight right passed Virgin Galactic's Spaceship-2 as we headed to the Vertical Launch Area.

In a small building at the launch area CDT Chase Lewis and Mr. Maydell readied the second stage for launch, prepping ignition charges and configuring the avionics. Meanwhile the other members of the team erected the launch rail and mounted the booster by light of rental trucks. As the sun began to rise the excitement did to.

Figure 10: By Dawn's Early Light, a Rocket is Prepared for Launch

Shortly after the sun was fully above the horizon, the team and spectators gathered for the range safety brief. The brief was given by Dr. Bill Gutman, Spaceport America's Director of Aerospace Operations, and it laid out procedures for launch and actions in case of an anomaly occurred. Following the brief, the airspace was closed, and the launch was imminent. At just passed 0600 the range was hot, the pad was cleared, and the countdown began. 3, 2, 1…a pause and a rocket screaming skyward drawing a smoke trail behind. Waiting, waiting, waiting, and no second stage ignition. The team gathered as Mr. Maydell passed the last know

[3] On 29 APR 2021, West Point Academic Departments will conduct the 22nd Annual United States Military Academy Projects Day to showcase the intellectual capital of cadets and their important work with faculty and external collaborators while providing an opportunity to strengthen their role in the academic community, to exercise self-reflection to deepen their knowledge base, and to celebrate bold innovation. The event also gives cadets a chance to explore majors, learn from examples, and fulfill an integrative experience requirement. Join us as this event takes place across the world between cadets, faculty, staff, research partners, stakeholders, and friends of the Academy using video conferencing solutions.

coordinates from the GPS. Again, the rental 4x4 convoy was off in a cloud of dust headed toward the dropped pin on Google Maps.

From launch to recovery was under two hours. The team found the second stage in a small park area south of the launch site. Initial indications were the minimum safe altitude was incorrect and inhibited the second stage ignition. Despite the anomaly, the disassembly of the second stage revealed a fully intact second stage ignition system, to include the cadet manufactured pellets in the chamber. Everything had survived a 30G acceleration off the pad. Inspection of the fin section, which has broken into a couple pieces upon impact with the ground, showed evidence of contact with the rail. The team loaded up and rushed back to the Vertical Launch Area to review the data and the video of the launch.

Figure 11: First Launch Sustainer Recovery

The slow-motion replay of the video showed conclusively that the sustainer fin had struck the rail. It also showed a something unexpected. The spin rate and torque on the rocket is almost immediate and when the booster reached its limit on the rail the sustainer continued to spin at the interstage coupling. To ensure the fins did not strike the rail during the second launch the rail had to be shortened from its 16 ft length. The team calculated that a 10 ft rail would provide adequate stability for the second launch.

SPEAR-HRT split, one team would attack the rail, another team would harvest the ignition system and avionics from the first rocket. In the meantime, Team BPN would continue their work producing pellets on site, a validation requirement of their research project. The faculty advisors would support where needed and ensure cadets continued to work safely as fatigue would be setting in from long work hours, little sleep, and some jet lag from the travel.

Around 1100, the shortened rail was easily erected. The booster was set, and the sustainer was mounted. Again, the pad was clear, and the range was hot. The level of anticipation was palpable. It was the last chance at the space shot. For the firsties on the capstone team there would be no next year. Shortly before the launch window closed; 3, 2, 1, BLAST OFF! Once again, the booster let out a thick trail of smoke as it streaked skyward, straighter this time. The smoke from the booster stopped as the rocket continued in the coast phase. There was long pause that felt like forever. Then, a second smoke trail as the second stage ignited and the sustainer got a 45 g kick through the stratosphere. Cheers erupted from the team. All their work was on display miles above the earth and climbing.

Figure 12: Second Launch

A line-of-sight GPS transmitter is part of the onboard avionics package. As the rocket reached apogee the telemetry data was unclear. The team looked up anxiously as CDT Lewis and Mr. Maydell called out altitudes as the sustainer came down, hopefully under parachute. Contact with the rocket was spotty. A set of coordinates. The team threw it into Google Maps. Wow, that seems like a long way off. One more set of coordinates, then nothing. The location was showing the same general area. It was time to go hunting for the rocket, but the app was showing it was significant drive to get there. We needed verification before we went.

SPEAR-HRT took to the hills nearby. Mr. Maydell began making phone calls to see if he could secure an aircraft and pilot willing to take him up to try to get contact with the rocket before the batteries ran out and the second stage was lost. The cadets had no luck from the nearby hills. This meant there was a high probability that the rocket was near the last set of coordinates it sent, which indicated a position two ridge lines over. It was accurate the first time and should be this time, but the signal was being blocked by the

mountains. Searching from the air would give the team the best chances for recovery.

As luck would have it, the weather was beautiful and a crew chief that works for Virgin Galactic was going flying. Mr. Maydell was off to the airport. About 45 minutes later the team was tracking Mr. Maydell on Flightradar24 when they received a text with coordinates. Then a picture showing a solid contact. The race was on. Late in the afternoon, 500 ft from an unimproved road, the team raised their rocket in victory.

Figure 13: Second Launch, Second Stage Recovery.

The next morning, the team met in the IGH lobby and had their first look at the onboard telemetry data. The rocket had not traversed the Kármán line. The preliminary data showed and apogee of approximately 84 kilometers. It was close but not quite there. Despite not making the altitude the overall mission was a great success. The team learned a great deal about what it takes to launch a rocket successfully. They were able to launch, recovery, and launch in under 6 hours. The capstone team's ignition chamber design was validated. Team BPN also validated the performance of their cadet manufactures pellets and onsite manufacturing procedures. The success of SPEAR-HRT has laid the foundation for continued rocket capstone projects and has inspired cadets from all around the Corps to get involved in SPEAR and other research opportunities.

EXTENDING THE SPEAR

Throughout the spring semester I worked to reinvigorate SPEAR as a club activity with the vision to grow into an academic club within the Department of Physics and Nuclear Engineering. Despite the reputation of being a "hard" department in terms of academics the department's motto, "Everyone has a home in the House of PaNE," is a testament to the true culture in Bartlett Hall. This inclusivity extends to SPEAR through the multidisciplinary nature of space science. I look for cadets who have an interest in space and I find a way to link their academic focus to space related research. While SPEAR-HRT and the rocket has been at the forefront and is the initial draw for many cadets, they are intrigued when they come to their first club meeting and see there is a link between space science and almost every other academic discipline at the Academy.

The SPEAR club was extremely successful during its initial semester. The cadets took the lead and began to make CDT Cea's vision come to life. Cadets were introduced to multiple space related research activities. Some cadets immediately became involved in supporting SPEAR-HRT. Others found activities that were more in line with their interests and skills. Many were able to earn SP89 credit late in the semester because of the work they did. The SPEAR club was a feeder for space related research. Underclassmen, who would have otherwise not known about the opportunities, were jumping right in on highly technical research. All the cadets who joined during the semester brought excitement and passion to the group and it was infectious.

Figure 14: Jared Isaacman Flyer

In addition to acting as a feeder for cadet research SPEAR is focused on development of space professionals and leaders of character. Cadets were able to research out and secure two phenomenal speakers for professional development talks during the spring semester. The first talk was given by Dr. Alan Stern[4], lead of the NASA New Horizon's Mission. He is extremely excited about the cadet's research effort and has continued dialogue with some of them, providing recommendations to help them in their quest for knowledge. The second talk was given by Mr. Jared Isaacman, Commander and Benefactor of the Inspiration 4 Mission. Mr. Isaacman[5] spoke to cadets about his reasoning for establishing this historic space mission and the type of leadership that has led to his success. We hope to host both fine gentlemen in person in the future.

Cadets in SPEAR will also have an opportunity to receiving training from department lab technicians on the vast array of equipment available to them to support their research activities. PaNE plays host to a clean room, a woodshop, a machine shop, an electronics shop, and a welding room. Within the various shops are a multitude of precision fabrication tools cadets can learn to use. CME has all the above and more on a much grander scale, all accessible to cadets.

Finally, SPEAR is focused on outreach and collaboration. The club has started working with AFROTC at Manhattan college as well as the Merchant Marine Academy to see if their cadets can be included in some of the space education and professional development opportunities offered by SPEAR in the future. Cadets from both organizations can commission directly in the United States Space Force and there is a growing interest in space related education amongst their cadets because of that. Through the connection with SPEAR cadets from the Merchant Marine Academy may attend the Army Space Cadre Basic Course, known as Space Military Individual Advanced Development, hosted at West Point this summer.

Space is in the news every day. Space education is critical to the success of the nation where space is a contested domain. It is also imperative that we look to space for the future of humanity. One group of forward-thinking cadets saw an opportunity in a growing field and were able to leave a legacy for those following in their footsteps.

HIGHER, FASTER, FARTHER

Following the successful launch of the second rocket in May the first-class cadets shifted their focus to gradation. A new capstone lead was anointed, and CDT Easton Bolin took the reigns of SPEAR-HRT. CDT Bolin accompanied the team on the recent launch and the conversation about the goals for AY 22 were already underway. At the time there were only a few things that could be improved when keeping with COTS motors. The decision was to refine the sustainer nozzle design, so it is optimized for flight at altitude. This will be the focus of the capstone. However, much must be done to get to a launch as our experience has shown. The bottom line is we know we can do it and we can do it better. Plus, we have a full planning cycle to make it happen. We will go higher, we will go faster, and we will go father than before.

Figure 15: SPEAR-HRT on The Plain

[4] https://alanstern.space/about/

[5] https://inspiration4.com/crew#jared

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There is a long list of recognition and thanks that is behind the story in this paper. This year's successes could not have happened without the dedicated team of faculty advisors and mentors across three academic departments: CME, PaNE, and CLS. LTC(P) Jamie Bluman, CME, is a master of making things happen. He will never take no for an answer when in comes to supporting his cadets and his faculty advisors. COL Pete Chapman, PaNE, who lets me run wild with any "good idea" I have and supports the cadets that do the same. MAJ Jeremy Paquin, CME lead capstone advisor and trip section OIC, an officer with an unmatched drive which is reflected in his highly impressive resume. Best of luck to him as he works through the astronaut candidate selection process. MAJ Nate Humbert, CME capstone co-advisor, along for the ride this year and lead next year. I hope he writes the paper for AY 22. LTC Dan Baha, CLS, who spent countless hours in the lab making sure we did not blow ourselves up. I wish we would have met sooner but I am sure he will enjoy Hawaii.

LTs Brandon Cea, Chase Lewis, Nick McDonald, and Connor McQueen. It was an absolute pleasure working with the gentlemen on their culminating event for their major and their 47-month experience. I am sure every one of them will do great things for the Army and the nation. I hope at least one comes back to USMA to teach.

Cadets Anthony Haynes and Michelle Szegda, together they are Team BPN. A CLS turned PaNE major, and a GIS major come together to start brewing explosives in the basement. It is something that could only happen here and I am glad I could be a part of it.

DISCLAIMER

The views expressed are those of the author and do not reflect the official policy or position of the United States Military Academy, US Army, US Air Force, Department of Defense, or the US Government.

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